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Title: Expansion of Organic Scintillator Capabilities for DRiFT Software

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Expansion of Organic Scintillator Capabilities for DRiFT Software

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ALDX

XCP-7: Radiation Transport Applications

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LA-UR-XXXXXX

Who am I?

- Educational Background
  - B.S. in Nuclear Engineering from University of Tennessee, Knoxville (2018)
  - M.S. in Nuclear Engineering from University of California, Berkeley (2020)
  - Prospective PhD in Nuclear Engineering from University of California, Berkeley (~2022)
- Division: ALDX
  - Group: XCP-7
  - Mentor: Madison Andrews
- Research
  - DRiFT software development
  - PhD Research: Antineutrino Detection

THE UNIVERSITY OF TENNESSEE KNOXVILLE

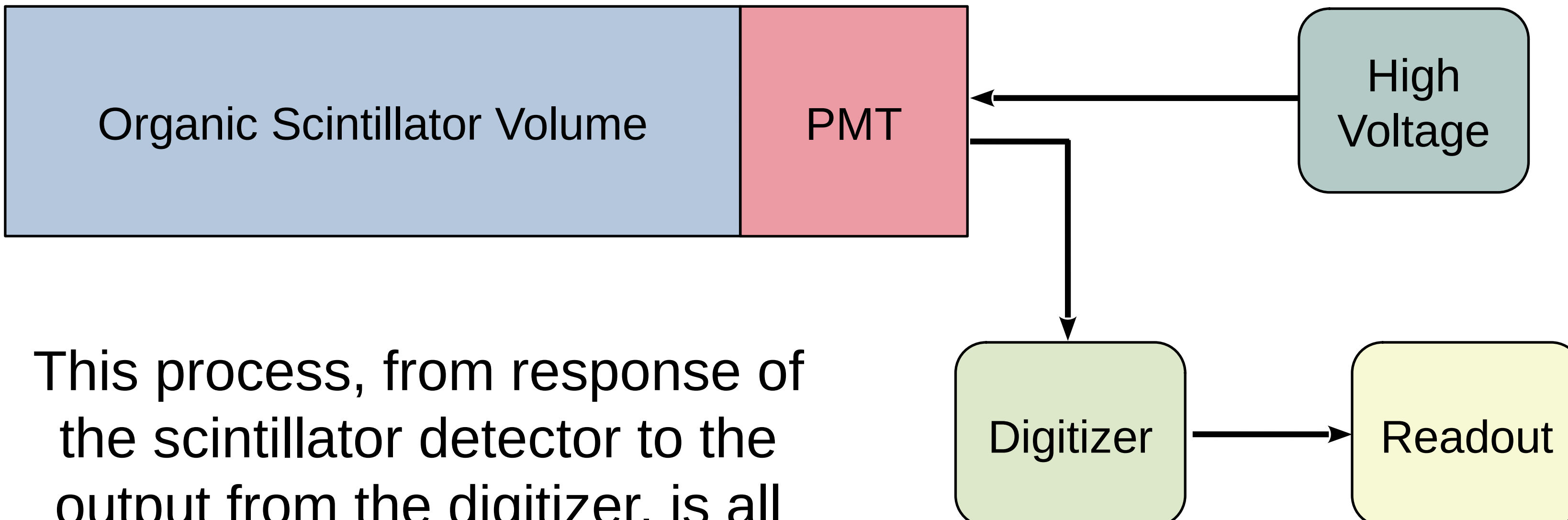
Overview

- Organic Scintillators Overview
- What is DRiFT?
- Recent Developments in DRiFT
- Future Prospects and Plans

Organic Scintillators

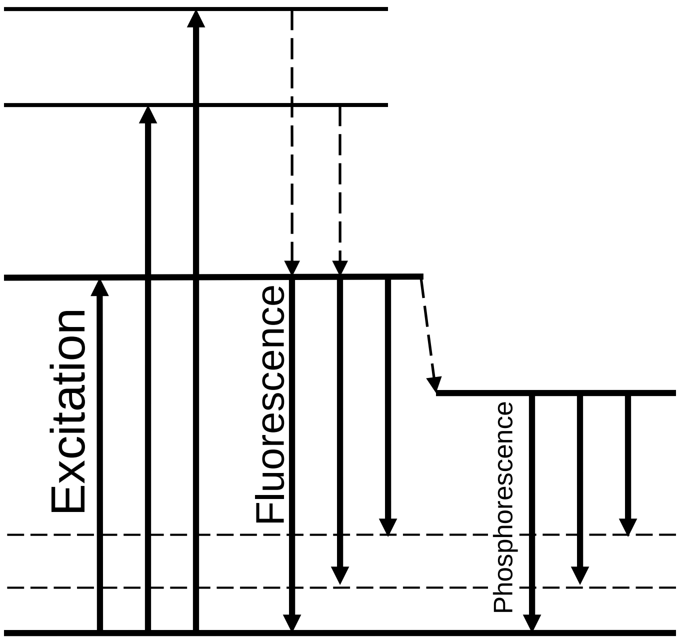
How do they work and why do we care?

Cross Section of an Organic Scintillator Detector



This process, from response of the scintillator detector to the output from the digitizer, is all modeled in DRiFT

Organic Scintillators: Overview

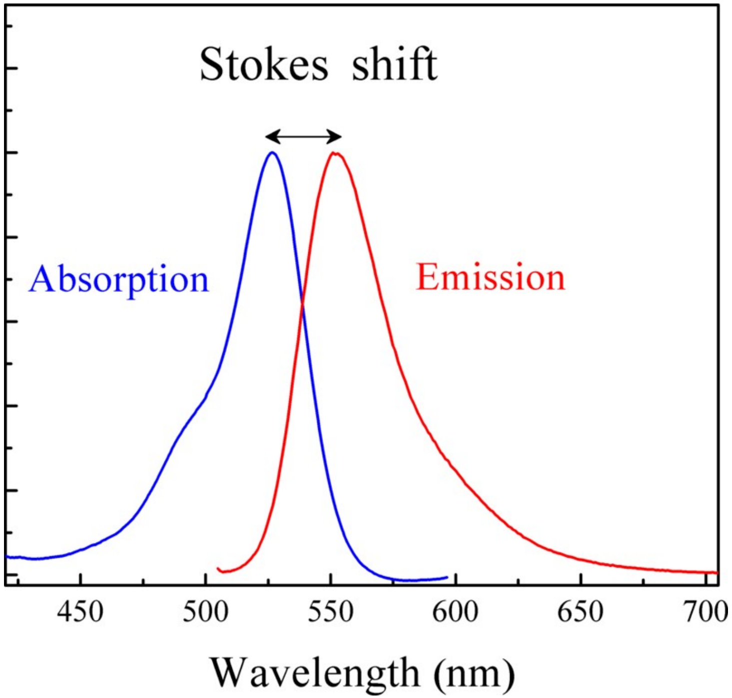


Scintillator **absorbs** energy from radiation and **de-excites** by emitting visible light

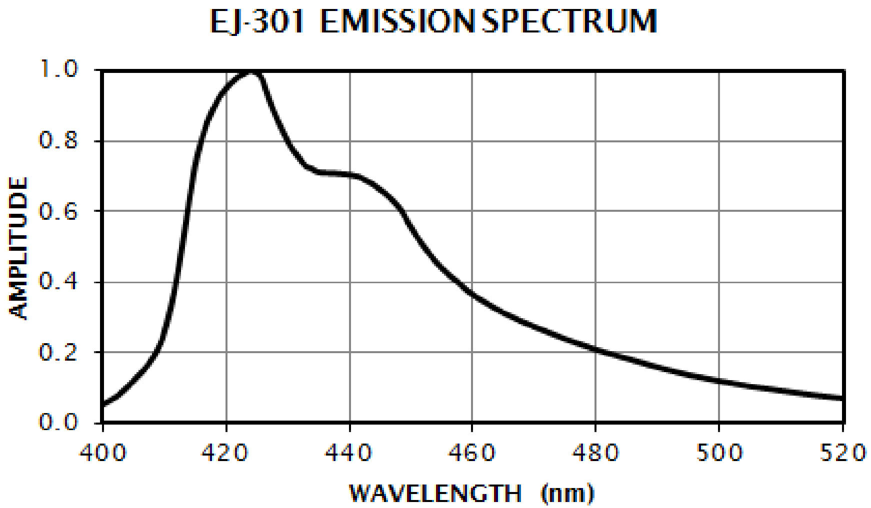
By National Nuclear Security Administration / Nevada Site Office - https://commons.wikimedia.org/w/index.php?curid=20990804

Organic scintillator is **low-cost** and easy to use in **bulk** and in various **detector geometries**, leading to many **safeguards applications**

Organic Scintillators: Emission Spectrum



By Sobarwiki, https://commons.wikimedia.org/w/index.php?curid=29474504



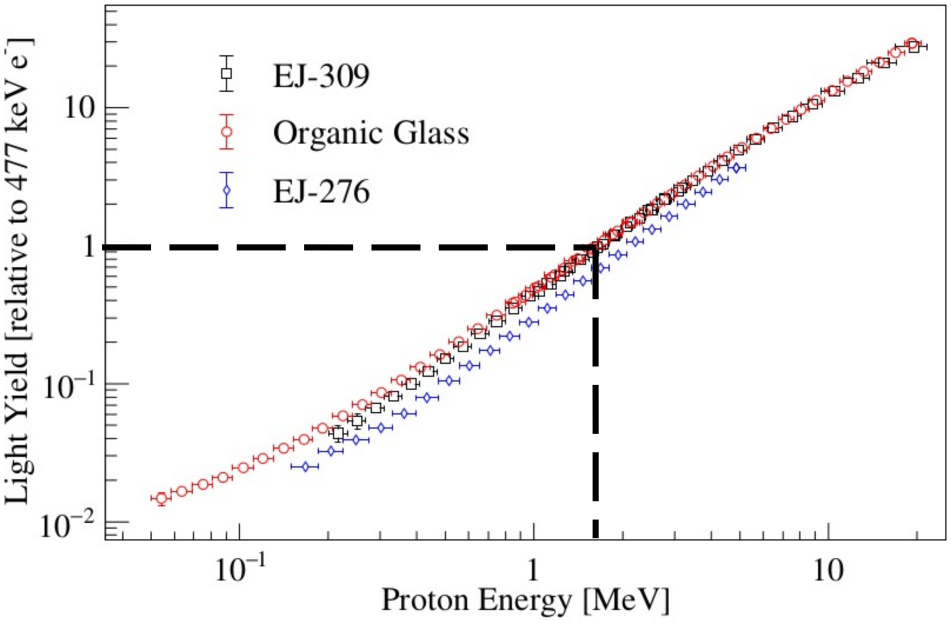
https://eljentechnology.com/products/liquid-scintillators/ej-301-ej-309

Stokes shift limits self-absorption, **emission spectrum** varies between scintillators

Organic Scintillators: Light Yield

Radiation of different **stopping power** creates characteristically different excitations

- Protons, deuterons, and electrons will all produce **different amounts of light** per MeV deposited
- Energy depositions are reported in **MeV electron equivalent** (MeVee)



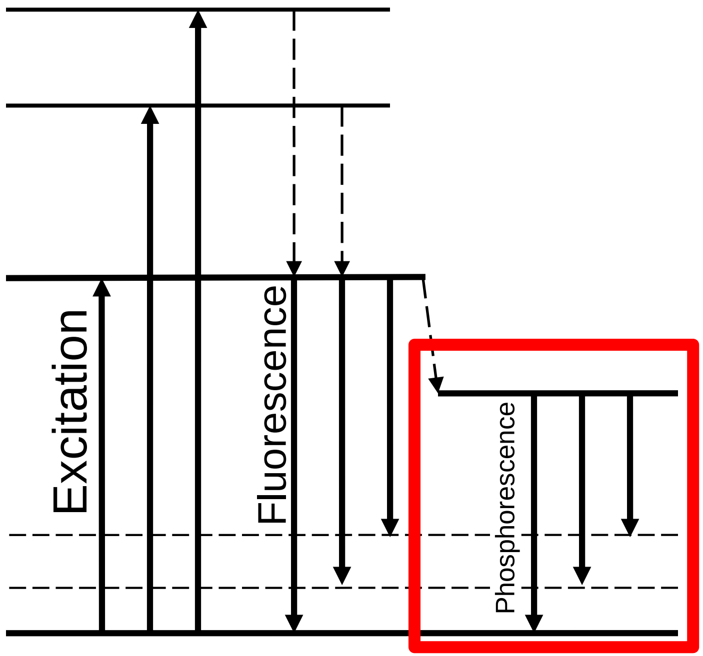
T.A. Laplace et al 2020 JINST 15 P11020

Organic Scintillators: Scintillation Efficiency

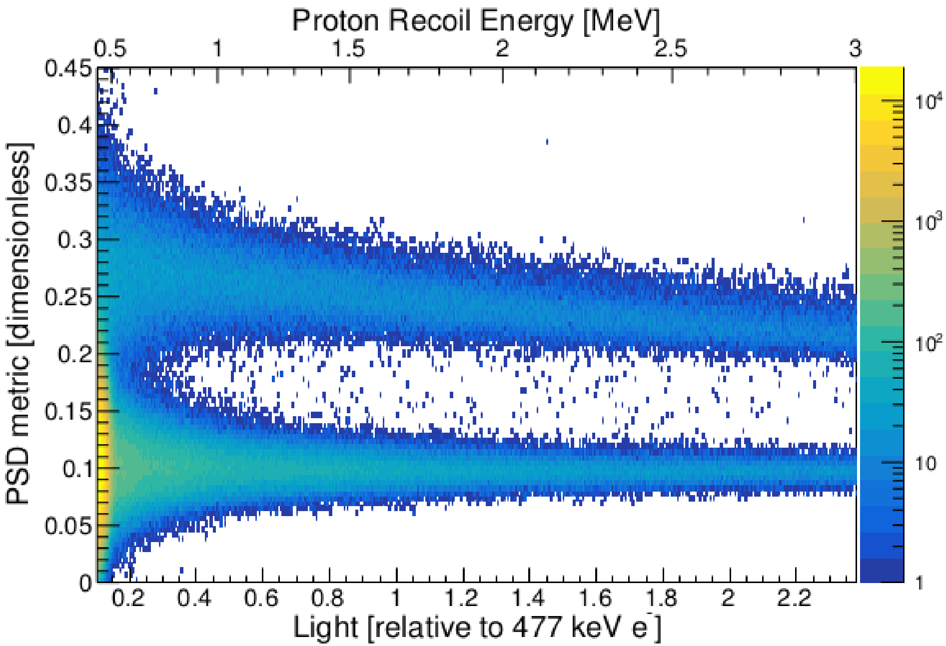
How efficiently is **energy** converted into **light?**

- De-excitation can occur **without** emission of optical photons, called **quenching**
- **Impurities** in the scintillator will often increase quenching
- Usually reported in **photons/MeVee**

Organic Scintillators: Pulse Shape Discrimination



Protons create more long-lived phosphorescence creating a **distinct, longer tail** than electrons



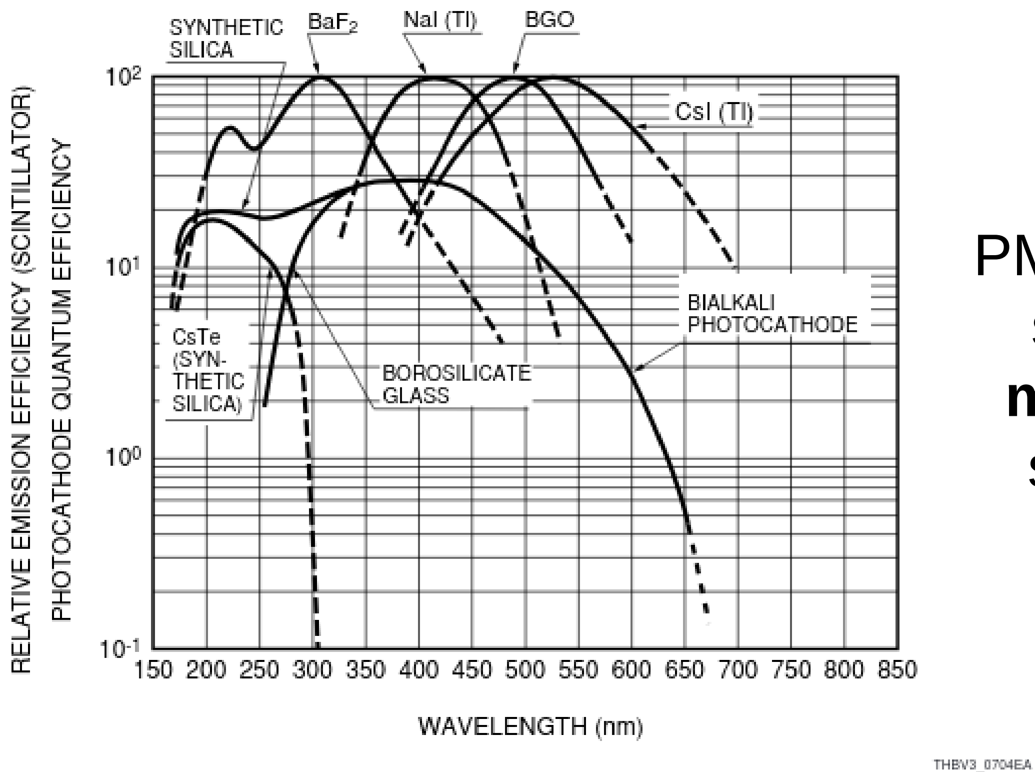
T.A. Laplace et al 2020 JINST 15 P11020

Allows for separation of neutron events and gamma events based on **pulse shape**

PMTs: Quantum Efficiency

Visible photons → Electrons

Depends strongly on **wavelength** of the light

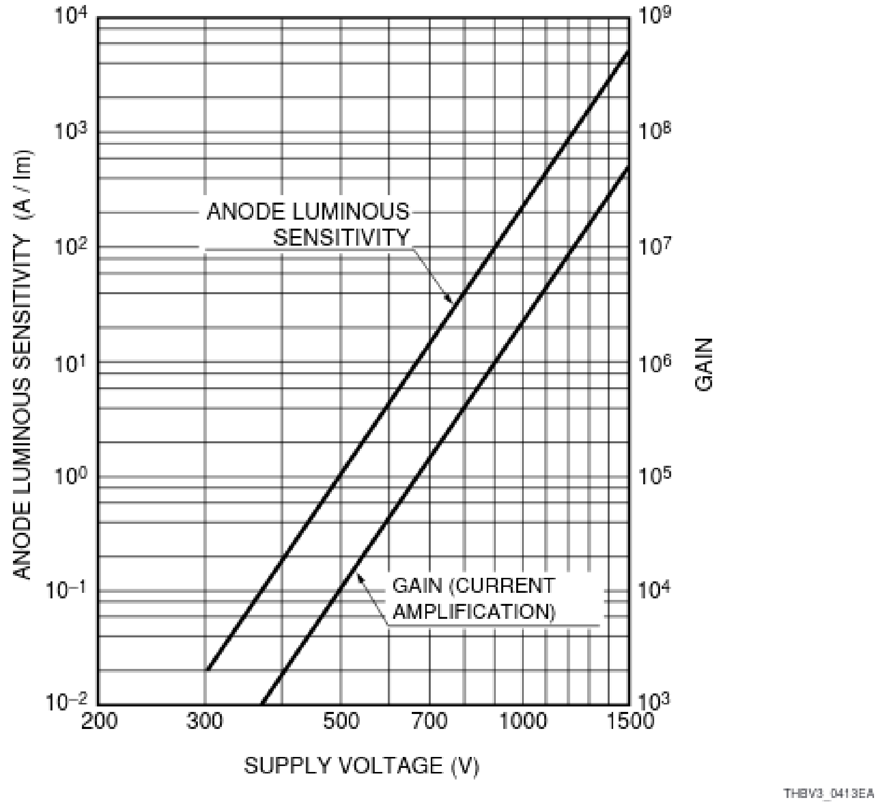


Hamamatsu Photonics, 2007

PMT selection should be **matched** to scintillator choice

PMTs: Gain

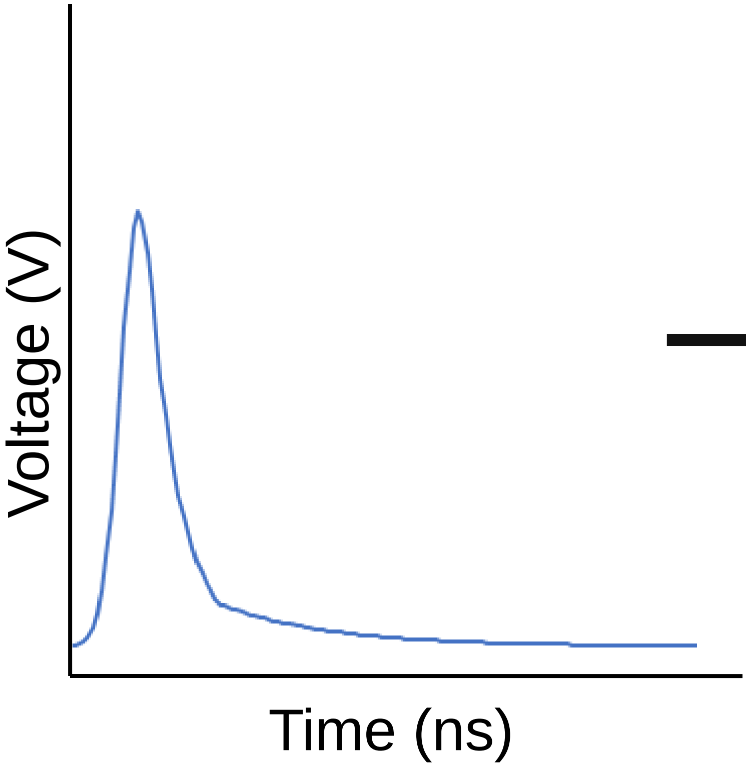
Few Electrons ⟶ Current Pulse

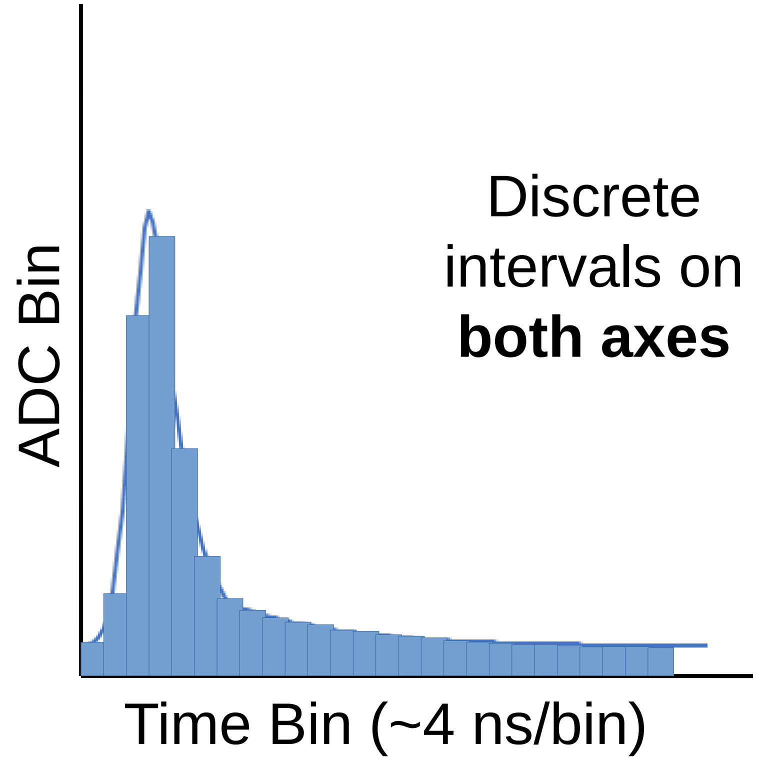


Hamamatsu Photonics, 2007

Digitizer Effects: Principles

Analog Signal → Digital Signal

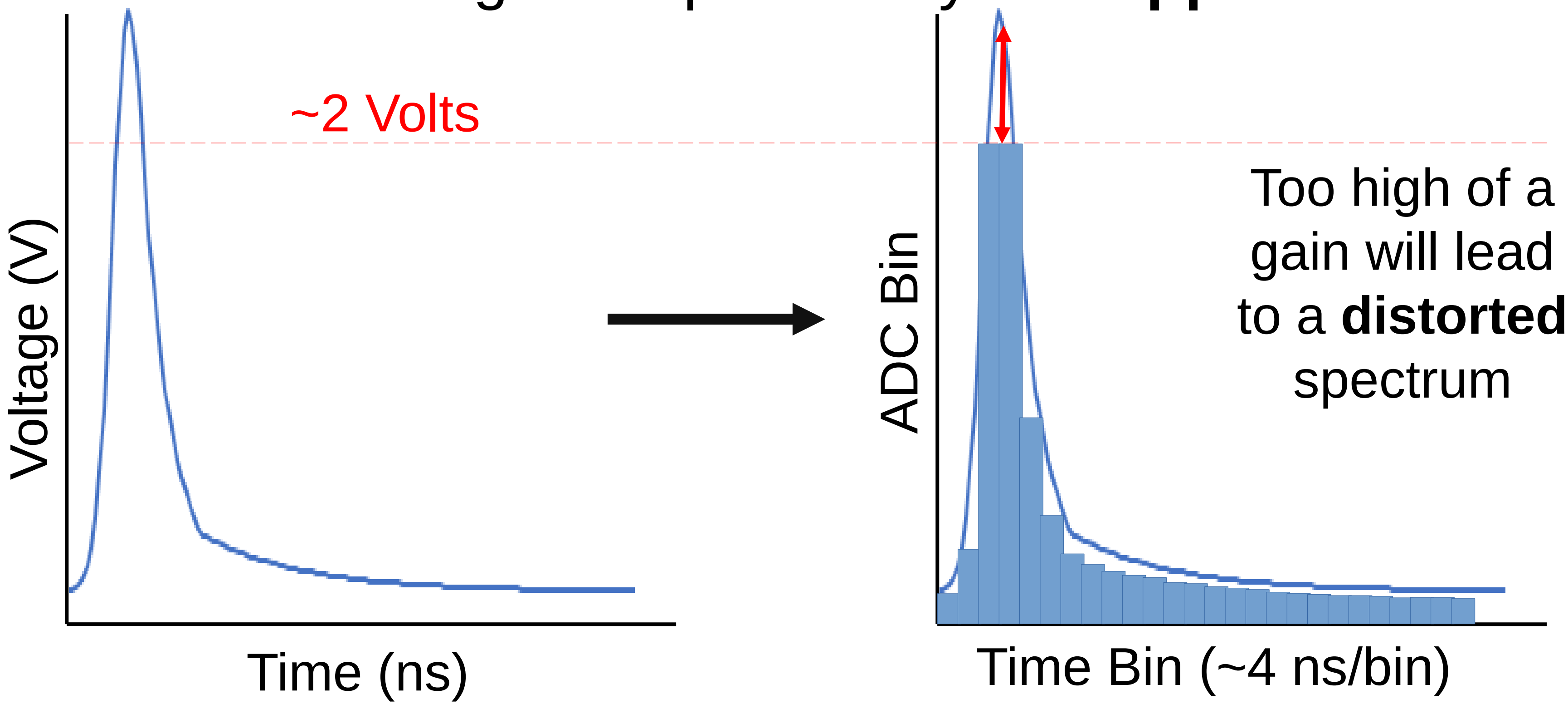




Discrete intervals on **both axes**

Digitizer Effects: Clipping

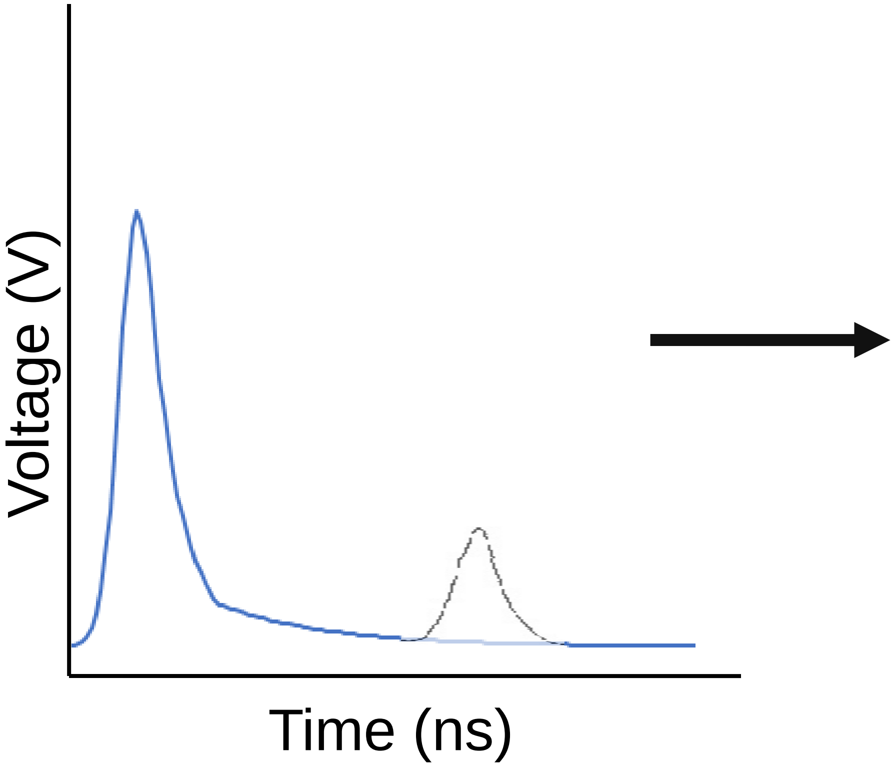
Digitizers have a maximum voltage they can record; too large of a pulse may be **clipped**!

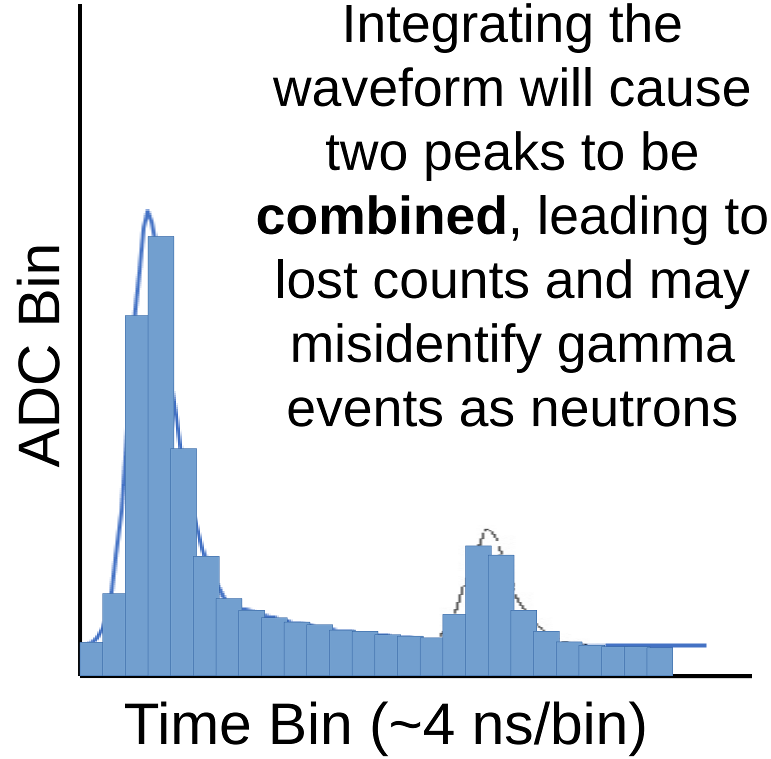


Too high of a gain will lead to a **distorted** spectrum

Digitizer Effects: Pileup

Two pulses close together will cause **pileup** and be recorded as one!





Integrating the waveform will cause two peaks to be **combined**, leading to lost counts and may misidentify gamma events as neutrons

DRiFT

A Detector Response Function Toolkit

MCNP®6.2: A Powerful Tool for Radiation Transport Simulations

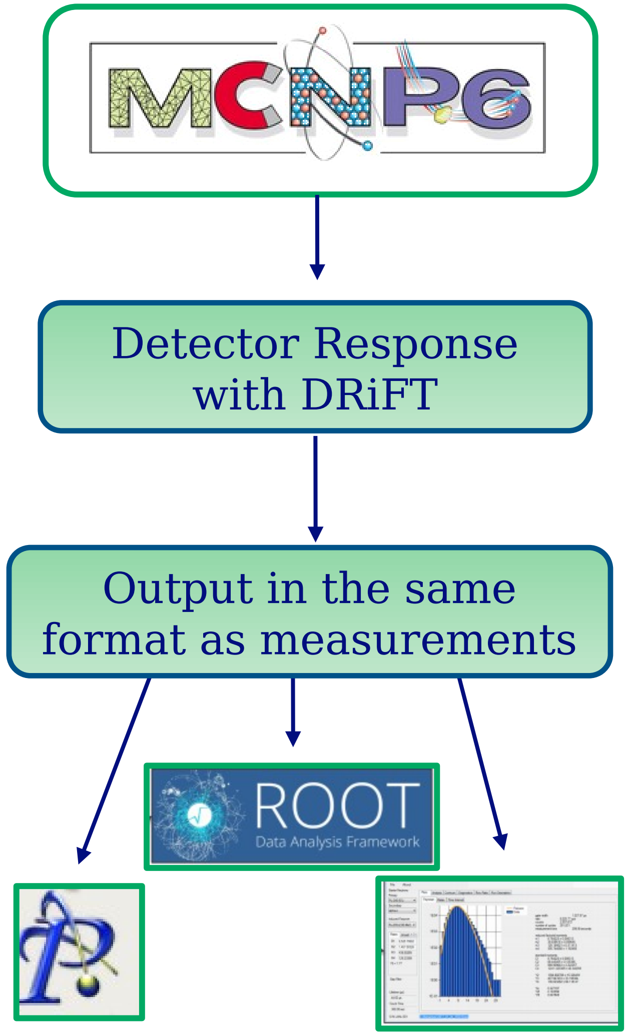
Excellent simulation of neutron (and gamma-electron) interaction in materials

but

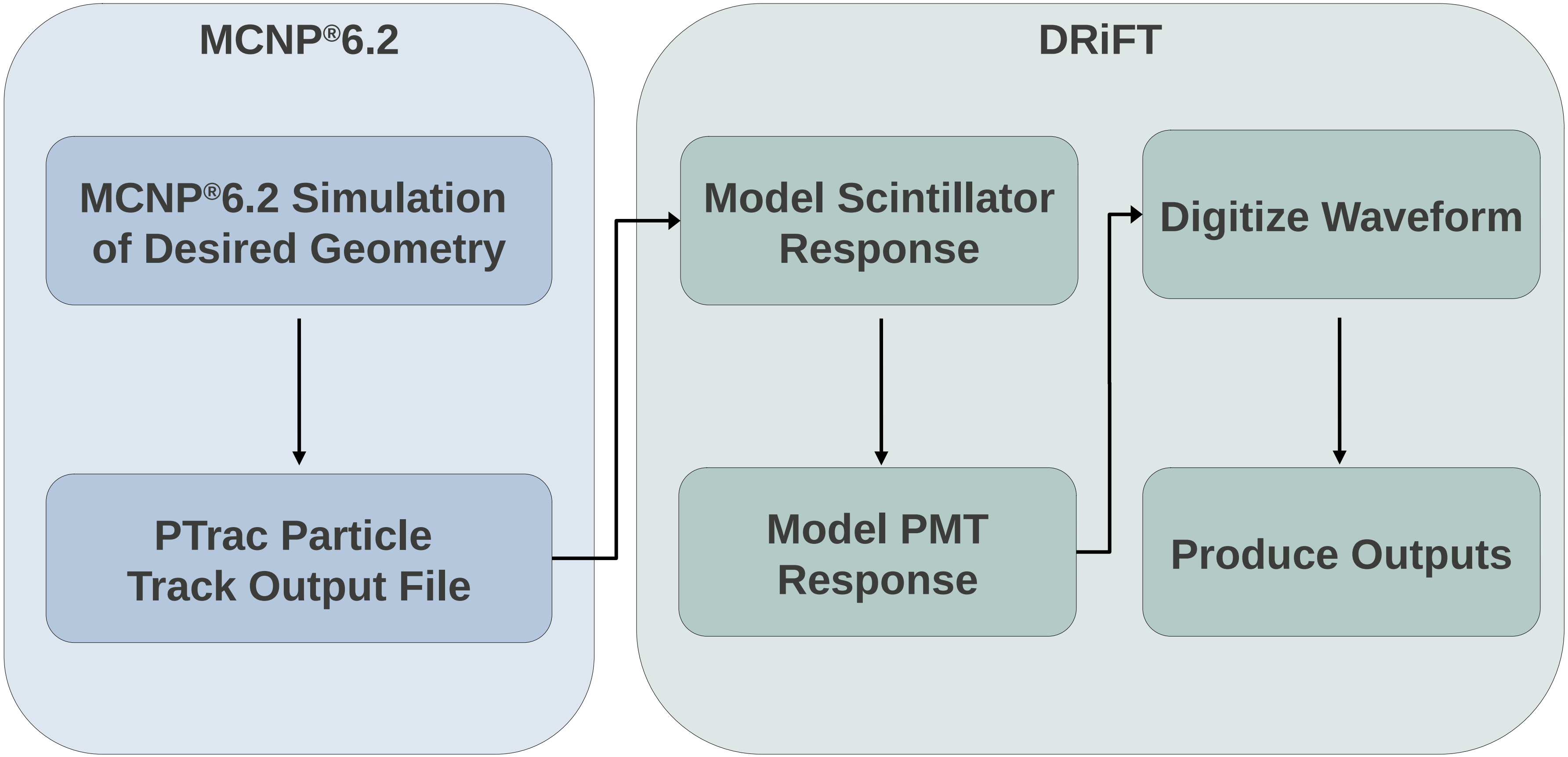
limited capability to model realistic detector response to these interactions!

DRiFT: Goals

- Post-processes MCNP output to create realistic detector response
- Modular to allow user customization
- Simple framework for addition of desired scintillators and PMTs



DRiFT: Process



DRiFT: User Input

```
[global]
modeltype=event
datasource=mcnp
ptrac_type=bin
#Name of the PTRAC file you want to process
datafile=omcnp_p
#datafile is the file name of the mcnp ptrac output
det_cells=1

[SourceInformation]
call=SourceInformation
multi_src=yes

[Scintillation]
call=Scintillation
detector=EJ301
optical_transport=0.6
pmt_type=9821B
voltage=1500
divider_option=B

[Digitizer]
call=Digitizer
voltage_range =2.0
digitizer_samples=256
resolution=16384
ter_res = 50
DC_offset = 0.1
start_point = 0.1
digitizer_rate=500.e6
trigger_ADC=70
PSD=yes

[WriteOutput]
call=WriteOutput
outputs=source_e count det_pulse det_cell corr_count time PSD cells_history
output=output.txt
```

[global]: What should DRiFT look for in the PTRAC file?

[SourceInformation]: Should DRiFT track source particles (for correlated events)?

[Scintillation]: How should the detector and PMT be modeled?

[Digitizer]: How should the waveforms be digitized?

[WriteOutput]: What information should be output?

Timing (Source Activity) information can also be defined

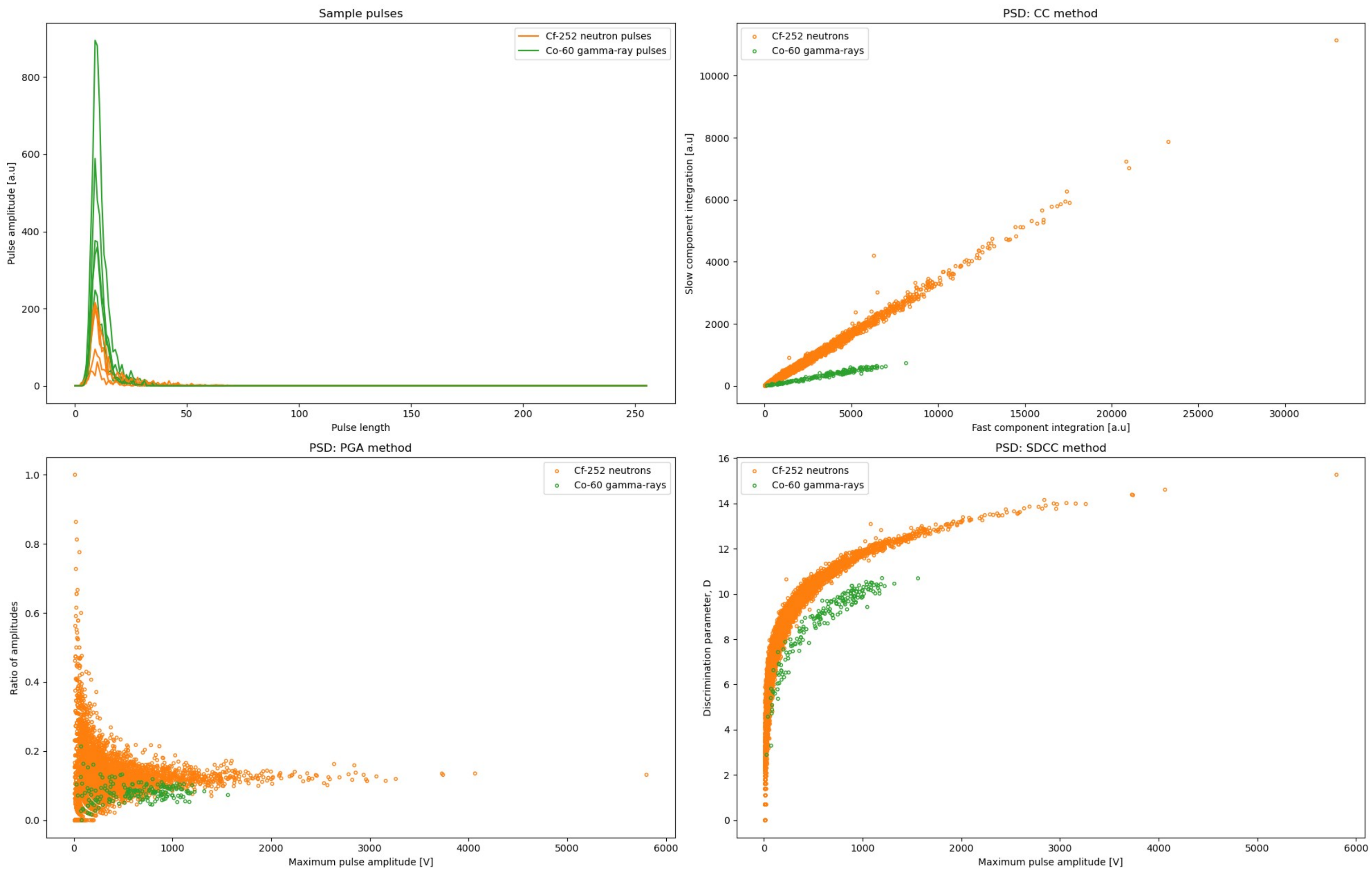
DRiFT: Output

source_e (MeV)	NPS	det_pulse (MeVee)	det_cell	corr_count	time (s)	PSD	cells_history
1.63259	71	0.133547	1	no	7.39562e-09	0.212628	2 1
1.814	354	0.255438	1	no	3.94077e-09	0.216505	2 1
3.29549	640	0.484216	1	no	3.26886e-09	0.234059	2 1
1.66616	763	0.105647	1	no	4.30608e-09	0.169014	2 1
0.879835	774	0.0920073	1	no	9.41205e-09	0.218329	2 1
2.02652	1001	0.440321	1	no	4.41343e-09	0.255421	2 1
2.76593	1016	0.606231	1	no	3.3331e-09	0.234813	2 1

What outputs are printed is configurable in the input file

A sample waveform can also be printed, if desired

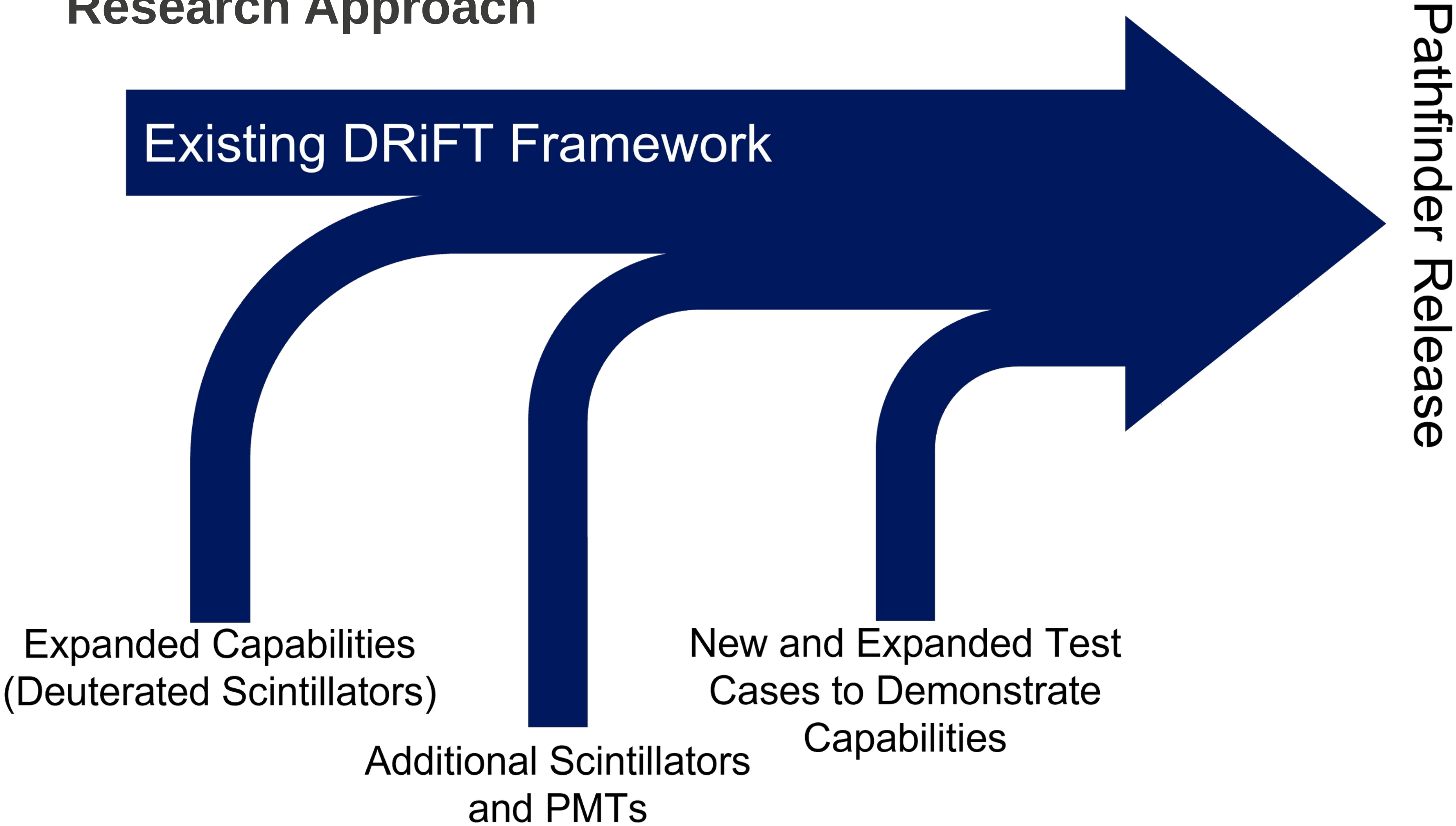
DRiFT: Example Waveforms



Recent Developments

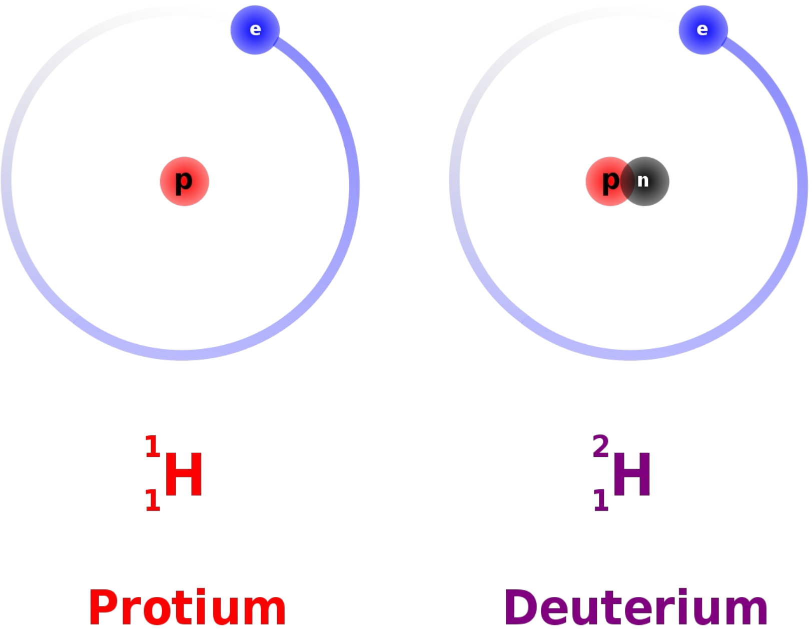
An Expansion of Organic Scintillator Options and Capabilities

Research Approach



Expanded Capabilities

https://eljentechnology.com/products/liquid-scintillators/ej-315



Dirk Hünniger- https://commons.wikimedia.org/w/index.php?curid=46295940

Light output and pulse shape looks different for recoil **deuterons** than **protons**

Additional Scintillators and PMTs

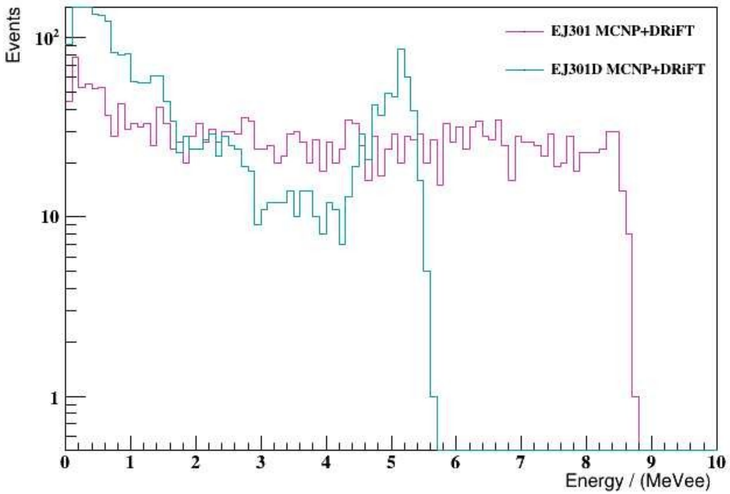
- 7 new scintillators (including 3 deuterated scintillators) with emission spectra, light outputs, and scintillation efficiencies
- 6 new PMTs with gain curves (for both A and B dividers) and quantum efficiency (often of several variants)
- Added documentation to guide users on adding their own scintillators and PMTs

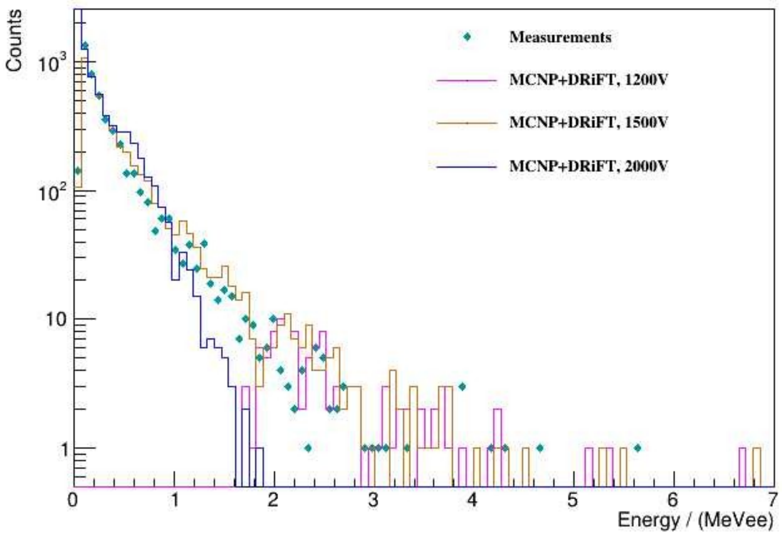
Expanded Test Cases

- Cleaned, developed and expanded 4 test cases of various detectors exposed to different radioactive sources
- Created 3 new test cases demonstrating:
  - A comparison between newly added scintillators
  - The new deuterated scintillator capability
  - How to implement new scintillators and PMTs using data tables

Summary of Results

Example deuterated scintillator test case shows effect of deuterium on response





DRiFT shows how over- or under-biasing the PMT will distort the spectrum (measurements are at 1500V)

Other Notable Work

- Expanded documentation, particularly on the process of adding new capabilities and on running test cases
- Created a new version of the code intended for public release
- Removed dependency of new version on ROOT to improve usability
- Began work on creating installation scripts for the code to operate on different operating systems

Future Work

- Release of DRiFT code on Github for wider use
- Development and expansion of semiconductor and gas detector capabilities
- Further development and refinement of scintillation, PMT, and digitizer response

Disclaimer and Auspices

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Contact Information

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